Journal of Engineering Research and Reports

15(4): 45-60, 2020; Article no.JERR.60396
ISSN: 2582-2926

Analysis of Petro-Physico-Mechanical Properties of Coarse Aggregate and Its Implications on the Performance Characteristics of Concrete

Larry Pax Chegbeleh[1*], Lawrence Opanin Nkansah[1], Frank Siaw Ackah[2,3] and Richard Adams Mejida[1]

[1]*Department of Earth Science, University of Ghana, P.O. Box LG 58, Legon-Accra, Ghana.*
[2]*School of Civil Engineering, Shijiazhuang Tiedao University, Shijiazhuang 050043, China.*
[3]*Key Laboratory of Roads and Railway Engineering Safety Control of Ministry of Education, Shijiazhuang Tiedao University, Shijiazhuang 050043, China.*

Authors' contributions

This work was carried out in collaboration among all authors. Author LPC hatched the concept, wrote the protocol and drafted the initial manuscript. Author LON conducted the initial investigations and gathered the data. Both authors FSA and RAM contributed to the writing of the manuscript and the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2020/v15i417164
Editor(s):
(1) Dr. Guang Yih Sheu, Chang Jung Christian University, Taiwan.
Reviewers:
(1) Emer T. Quezon, Ambo University, Ethiopia.
(2) Toderas Mihaela, University of Petrosani, Romania.
Complete Peer review History: http://www.sdiarticle4.com/review-history/60396

Original Research Article

Received 10 June 2020
Accepted 17 August 2020
Published 18 August 2020

ABSTRACT

The importance of concrete as one of the major materials in the building and construction industry cannot be over emphasized due to the myriad benefits and versatility to humankind. However, its performance characteristics on the stability of engineered structures have mostly been overlooked. In this paper, petrographic characteristics and physico-mechanical properties of ten (*n=10*) rock samples and some quantity of coarse aggregate representing one set of samples, each obtained from two quarry sites around Amasaman and Shai Hills in the Greater Accra Region of Ghana, have been investigated. This study aimed to determine the impact of aggregate size, content and type on the compressive strength of concrete. The study was conducted through petrographic and physico-mechanical properties analyses on the samples obtained. Petrographic studies were performed on the ten (*n=10*) rock samples from each quarry site, while the physico-mechanical

**Corresponding author: Email: lpchegbeleh@ug.edu.gh;*

property tests were conducted directly on the coarse aggregate. However, compressive strength tests were performed on cast concretes produced from aggregates with varying sizes and type obtained from the two quarry sites. Results of the petrographic analysis reveal two rock types: Quartzo-feldspathic gneiss and Granodiorites from Amasaman quarry and also two rock types: Gneiss and Meta-granite from Shai Hills quarry. Results of the physico-mechical properties tests are consistent with requirement of approved construction standards. Compressive strength tests show increasing compressive strength of concretes with increasing aggregate nominal sizes of classes A, B and C but show reduced compressive strength for aggregate nominal sizes of class D. It can therefore, be inferred that, aggregate size and content have profound impact on compressive strength of concrete. Also, aggregate type has influence on compressive strength of concrete, as observed in higher compressive strength of concretes produced from the quartzo-feldspathic gneiss and granodiorites than concretes produced from the gneiss and meta-granites.

Keywords: Aggregates; amasaman; concrete; petrographic features; physico-mechanical parameters; Shai Hills.

1. INTRODUCTION

An overview on the significance of concrete as reported by Shelton and Harper [1] suggests that, cement concrete is the most widely used construction material globally due to its strength, durability, and versatility properties. While the strength property of concrete is defined by the maximum load that it can withstand without failure, durability is a measure of its resistance to the physico-chemical attack emanating from the environment [2]. This particular property makes concrete well-suited for structures that are exposed to demanding and extreme conditions. However, concrete's versatility refers to its adaptability to a wide variety of purposes. The state of these properties determine the quality and performance of concrete. These properties depend largely on the physico-mechanical properties of the constituents of concrete, and make concrete robust and long-lasting option for use by numerous domestic and commercial settings. In the United States of America for example, almost twice as much Portland cement concrete is used as compared to all other construction materials combined. A play back of historic events involving big concrete projects in the U.S.A. include [1]: The Erie Canal construction, which marked the opening of the first natural cement works; the first rural concrete highway near Detroit, Michigan in 1909; the Grand Coulee Dam, which used nearly 10 million cubic yards of concrete, making it one of the largest Portland cement concrete projects in history. This is indicative of the significant role and widely use of concrete in infrastructural development. The situation on the significance and widely use of concrete as material for many construction applications is not different in Ghana. Concrete is an indispensable and widely used construction material across the length and breadth of Ghana whereby, cement concrete constitutes one of the major materials in large government construction projects and projects of private individuals. Many times, engineered structures have been known to fail spontaneously without influence of external stress. Some of these failures have even been observed in structures that are yet in their construction phases. The absence of external stress factors in these scenarios could suggest either poor ground conditions and/or incompetence in concrete or its constituents [3]. Many researchers [4–6] carried out investigative studies on the strength characteristics of concrete produced using different aggregate materials. These studies indicate that, the uses of poorly graded coarse aggregates in concrete matrix are some of the causes of structural failure due to the development of horny comb in the concrete. The constituents of concrete are a mixture of cement paste (cement and water) and aggregates (fine and coarse aggregates). Moreover, cement is known to be largely responsible for dimensional instability in concretes such as shrinkage and creep [3]. What then could be responsible for the myriads benefits of concrete? In concrete mix, aggregates are the major constituents, typically occupying about three-quarter of the volume of concrete with the coarse aggregate taking between 50% and 60% of the concrete mix depending on the proportion used [4]. It is suggestive to say that due to the greater percentage of coarse aggregate in concrete mix, aggregates are expected to have significant influence on concrete parameters and the overall performance of concrete [7]. The physico-mechanical properties of rocks used as aggregates for various construction works are very important parameters in any application for various engineering purposes. However, these properties depend on the petrographic characteristics (i.e. mineralogical composition, size, texture, shape and arrangement of mineral grains, nature of grains contact and degree of grain interlocking), alteration and degree of deformation of the source rock [7]. The properties of coarse aggregate have significant influence on the strength and durability of concretes. In concrete structures, the mix proportions of other materials and aggregate type determine the compressive strength of concrete. Compressive strength is a mechanical property, highly influenced by the mineralogical composition of aggregates and their degree of alteration [8–13]. Selection of the type of coarse aggregate in concrete is important in determining the quality and performance of concrete. It is therefore important to have detailed knowledge on the petrographic characteristics and geotechnical properties of aggregates. These properties have significant influence on the performance characteristics of concrete as good construction material.

The main aim of the present study was to investigate the impact of coarse aggregate size, content and type on the performance characteristics of concrete. This was achieved through the following objectives:

a. To investigate the petrographic characteristics and geotechnical properties of coarse aggregates
b. To investigate the effect of mineral composition of aggregates on the strength of concretes produced from these aggregates.
c. To conduct comparative studies on the physical and mechanical properties of aggregates from different quarries.
d. To determine the strength of concretes produced from different nominal sizes of aggregate from the same and different quarries.

1.1 Location and Climate

Samples for this study were collected from two quarry sites, Odumase and Goke. The Odumase site is around Amasaman, the administrative district capital of the Ga West Municipal District, located about 20 km from the capital city, Accra, Ghana. While the Goke site is around the Shai Hills, a suburb near the administrative district capital, Dodowa of the Shai - Osudoku District, located about 35 km from Accra. Both districts are in the Greater Accra Region of Ghana and are thus under the influence of the same climatic conditions of the study area as described in Chegbeleh and Ackah [14]. The area is characterized by two main seasons: the rainy and dry seasons. There are two rainy seasons: the major rainy season, which occurs between April and July, while the minor rainy season occurs between September and November. The entire rainy season is followed by a prolonged dry season which spans from December to March. Mean monthly temperature ranges from 24.7°C in August to 33°C in March, with an annual average temperature of 26.8°C.

1.2 Geological Settings

1.2.1 Geology of Amasaman

Amasaman is part of the Kibi-Winneba volcanic belt, and consists of andesitic lavas, amphibolites, basaltics flows, pyroclastics and granite-diorites plutionic rocks [15]. The Birimian metasediments and metavolcanics in the Kibi environs were intruded by different types of granitoids. These granitoids are represented by biotite granites, leucogranites, hornblende-biotie granites, pegmatoids and migmatites, two-mica granodiorites and gneissic biotite granites [16]. The gray, medium-grained biotite granites and granodiorites are foliated, with biotite as their major mafic minerals. The light pink to light grey biotite granodiorites are equigranular and foliated. Their major mineral compositions are quartz, plagioclase, alkali feldspars and biotite, and variably horneblende. Their minor mineral compositions are also greenish chlorites and pinkish garnets [17]. The most common features in most outcrops is mafic enclaves and composed mostly of amphibolites and gabbros. Two types of granitoids intruded the Birimian terrane of the Kibi-Asamankese area. These granitoids are Dixcove (Belt type) and Cape Coast (Basin type) granitoids. The dixcove type granitoids are dorminantly horneblende-to biotite bearing granodiorites to diorites, syenite and monzonite. The Cape coast-type granitoids are mostly composed of lesser horneblends and biotite bearing granodiorites. Mostly, these cape coast type granitoids are emplaced in the Birimian sedimentary basins. Also other types of granitoids include the Biotite and horneblende granitoids which are part of the Winneba-type and Potassium rich Bongo type granitoids [16,18].

1.2.2 Geology of Shai Hills

The breakup of the Rodinia supercontinent which resulted in the Pan-African (Neoproterozoic) orogens and encompasses the long Trans-Saharan belt which is interpreted to have resulted in the assembly of the NW Gondwana from different cratonic fragments [19,20]. In the south eastern part of Ghana and the adjoining parts of Togo and Benin, the southeastern segment of the Trans-Saharan belt is exposed and comprises the Dahomeyide rogeny. The principal tectonic elements of the Dahomeyide orogeny are (i) the deformed edge of the West African Craton (WAC) with its cover rocks consisting of craton-verging nappes and thrust sheets bounded by ductile shear zones (ii) the suture zone representing the eastern boundary of the autochthonous WAC (iii) exotic rocks that form the granitoids gneiss complexes east of the suture zone [21]. Granitic augen gneisses are mainly the rocks of the deformed edge of the WAC and are referred to as the Ho Gneiss. They are overthrust by rocks of the suture zone comprising of high-pressure mafic granulites and eclogites represented by the Shai Hills Gneiss unit [21–23].

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this study include rock samples (to prepare thin-sections for textural observation under a microscope), coarse aggregate (randomly sampled at different points from stockpiles of the two quarry sites for various geotechnical properties tests), fine aggregate (river sand, for use as concrete mix), cement, Ordinary Portland cement (OPC) as approved by Ghana Standard Authority (GSA) for building and construction (used to produce concrete for compressive strength tests) and water (tape water, potable and free from impurities such as silt, clay, acids, alkalis and other salts and organic matter for concrete mixing).

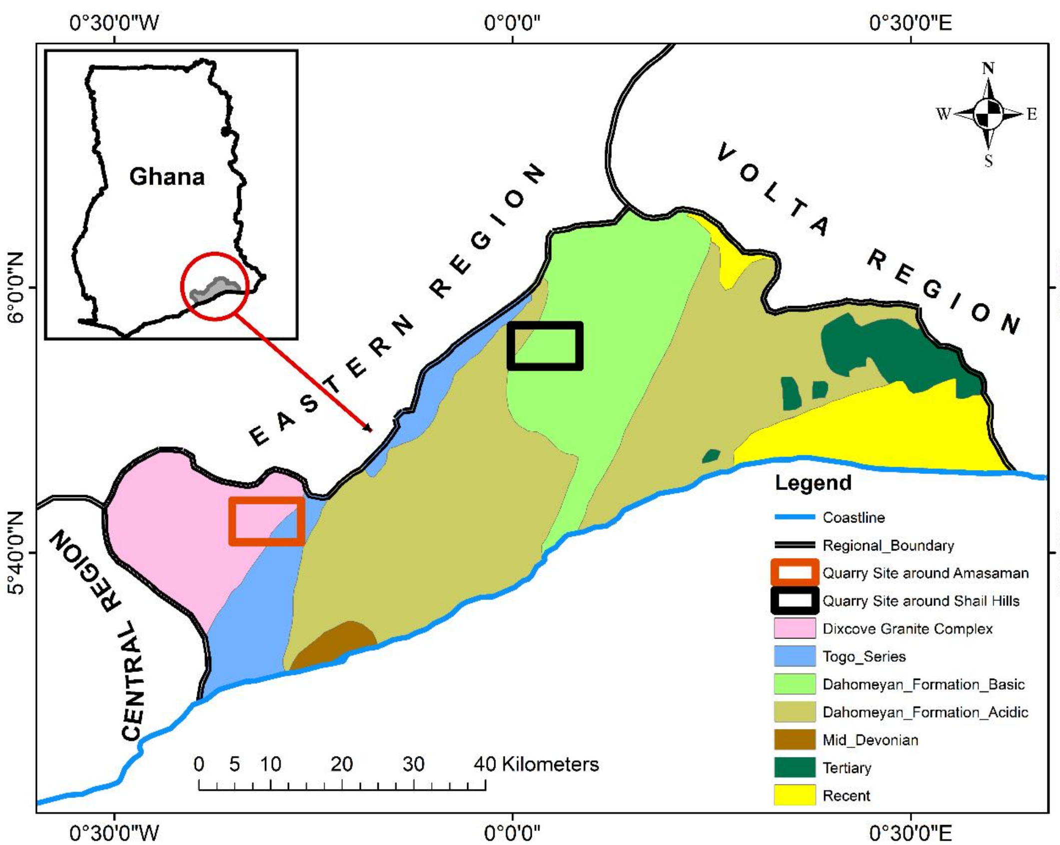


Fig. 1. Geological Map of Greater Accra Region of Ghana showing the Study Areas (Modified from Chegbeleh and Ackah [14])

2.2 Methods

A comprehensive methodological design comprising three major phases: Desk study, field investigation and laboratory analyses was constituted for the achievement of the broad objective of this study. The various tests conducted for the entire study include: Microscopic petrographic examination, Elongation index (EI), Flakiness index (FI), Aggregate impact value (AIV), Aggregate crushing value (ACV), Specific gravity (SG), Water absorption (WA), Los Angeles abrasion value (LAV), Compressive strength and Slump tests. A summary of the methods used is illustrated in the flowchart below (Fig. 2).

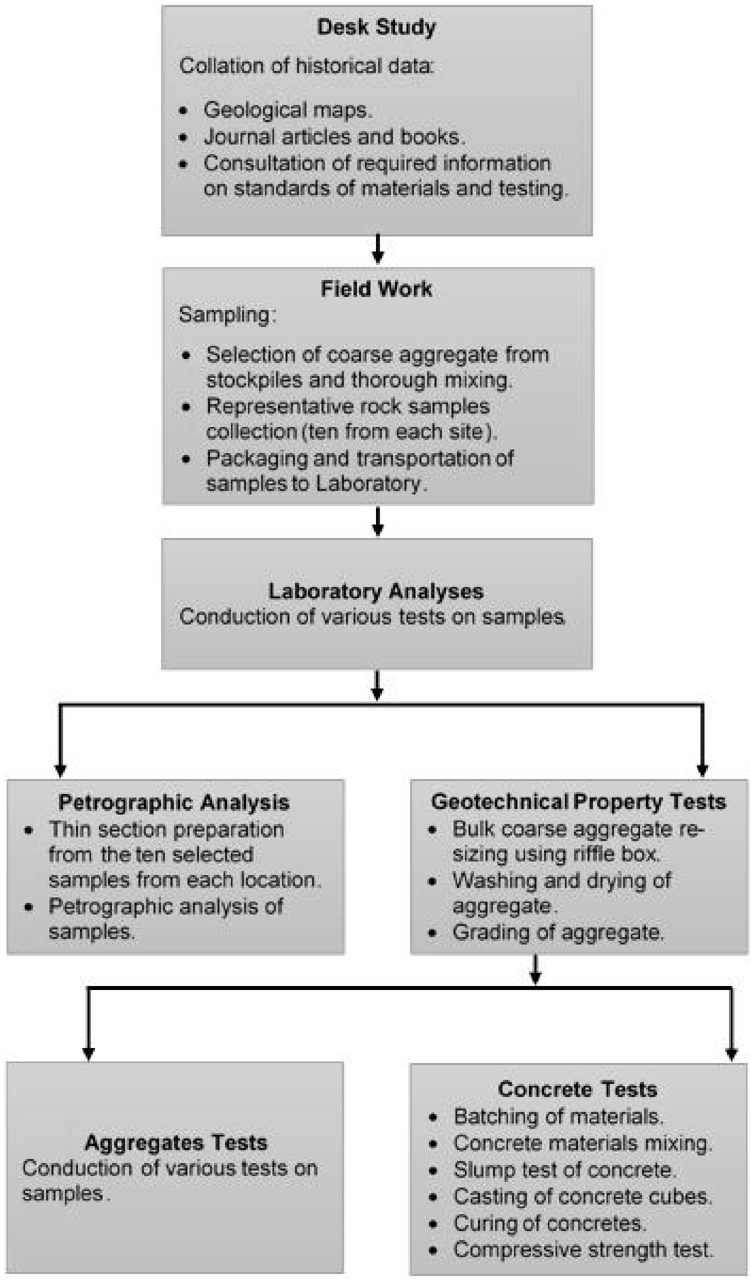


Fig. 2. Flowchart of overall methods used in investigations (modified from Chegbeleh and Ackah [14])

2.2.1 Desk study

A thorough review of pertinent literature was conducted. This involved collection of historical data such as geological maps and previous studies conducted in the area. The literature review also encompassed consultation of required information in order to understand the properties and characteristics of geological materials such as aggregates as well as information on standards of materials and testing. Generally, the literature review provided the necessary baseline information relevant to the study.

2.2.2 Samples collection and preparation

Samples for this study included ten (*n=10*) intact rock fragments and appreciable quantity of coarse aggregate forming one set of samples. Each set of samples was collected from two different quarry sites, the Odumase and Goke quarries, located around Amasaman and Shai Hills respectively. In order to have good representative sampling, the coarse aggregate was initially randomly picked at different points of the stockpiles from each quarry site and thoroughly mixed to achieve a state such that any amount of sample taken is the representation of the whole samples in the field. The ten (*n=10*) intact rock fragments were collected for petrographic analysis. All the samples collected from the field were properly packaged and transported to the laboratory for initial preparation prior to the various laboratory investigations. During samples preparation, large sized coarse aggregate was first reduced to sizes suitable for testing by a process called refilling. This involved the use of riffle box consisting of an even number of discharging chutes in alternate directions. Each bulk material was passed through the riffle box which divided it into two portions. The preferred portion was passed through the riffle box in a repeated process until the sample was reduced to the required size. The entire aggregate was thoroughly washed and dried in the laboratory for 48 hours to bring them to approximately saturated surface dry (SSID) condition, to reduce the effect of absorption.

2.2.3 Petrographic analysis

Petrographic study of rock is very vital in determining the physical and chemical features as it unravels the geological processes leading to the formation of rock. This includes study on mineralogy and texture which reflect the suitability of the rocks for different engineering purposes [24]. The ten (*n=10*) representative intact rock fragments selected, were prepared for petrographic analysis. The mineralogical and textural characteristics were examined in polished thin sections using the Nikon Optiphot-pol petrographic microscope for petrographic analysis [25–28]. Point counting and modal volume composition estimation by charts were used to establish the mineralogical compositions of the rocks [29].

2.2.4 Aggregate tests

The coarse aggregate obtained and prepared was then subjected to various physico-mechanical properties tests. The tests conducted on the coarse aggregate include [30–36]: Elongation index (EI), Flakiness Index (FI), Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV), Los Angeles Abrasion Value (LAV), Specific Gravity (SG) and Water Absorption (WA).

2.2.5 Concrete tests

Concrete tests were performed to investigate the effects of coarse aggregate size, content and type on the compressive strength of concrete. Compressive strength test, is a mechanical test that measures the maximum amount of compressive load a material can bear before failure. The test measures the ability of material or structure to carry the loads on its surface without any crack or deflection. The concrete tests involved initially producing concrete from mixed proportions of aggregates, cement and water and then subjecting the cast concretes to compressive tests after curing. Normal concrete cubes of dimensions 150 mm x 150 mm x 150 mm were produced from the two aggregate sources of different nominal sizes. For each source (quarry site), four nominal sizes of coarse aggregate were considered for this study: Class A (8 mm), Class B (16 mm), Class C (40 mm) and Class D (0-40 mm), with Class D sizes being used as a control experiment. C-25 concrete was chosen for the experiment and batching of materials was done using the mass method with a mixing ratio of 1:1:2:4 (water: cement: fine aggregates: coarse aggregates) for casting the concretes. Three (*n=3*) concrete cubes for each nominal size were prepared and tested at age 7, 14, and 28 days [37,38]. So, there are nine (*n=9*) concrete cubes for each nominal size of coarse aggregate. This implies a total of thirty six (*n=36*) cube samples for each quarry site were prepared for the compressive strength tests. After 24 hours of casting, the concrete cubes were removed from the molds and transferred to a container of water for curing. The samples were cured for a maximum of 28 days [39]. Compressive strength tests were carried out on the cured specimens at 7th , 14th and 28th day [40]. For each nominal size, the average failure load from the three cubes was used to estimate the compressive strength of concrete for the mix.

The strength of concrete of a given mix proportion is affected by the degree of its compaction. It is therefore important that the consistency of the mix be such that the concrete can be transported, placed and finished sufficiently easily and without segregation. A concrete that satisfies these conditions is said to be workable [41]. The workability of the concrete was determined by performing slump test. Concrete slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. It can also be used as an indicator of an improperly mixed batch. Slump tests were performed in accordance with standard requirement [42].

3. RESULTS AND DISCUSSION

3.1 Petrographic Analysis

Field descriptions and petrographic analysis were carried out to examine the mineralogical and textural characteristics of the aggregates. The petrographic studies of rock samples from the two quarry sites revealed two types of lithologies at each quarry site: Quartzo-feldspathic gneiss and Granodiorites from the Odumase quarry at Amasaman, and Gneiss and Meta-Granite from the Goke quarry at Shai Hills. Results of the petrographical and mineralogical studies are presented in Table 1 and Fig. 3.

Quartzo-feldspathic gneiss of the Odumase quarry around Amasaman appeared grey with pinkish tints and strongly foliated. It is compositionally banded with felsic bands alternating with mafic bands. The rock is relatively fresh, clean and structurally competent. It is coarse-medium grained and composed dominantly of quartz and feldspar with subordinate biotite and muscovite. The rock does not react with dilute HCl, which may indicate the absence of probably carbonate. From the thin section, the rock is coarse grained, recrystallized and foliated. It is dominantly composed of quartz together with microcline and plagioclase, with

Table 1. Modal composition of samples from the two quarry sites

Location	Rock type	Mineral	Volume %
Amasaman	Quartzo-feldspathic gneiss	Quartz	56
		Microcline	28
		Plagioclase	12
		Biotite	3
		Muscovite	1
	Granodiorite	Quartz	60
		Plagioclase	25
		Microcline	10
		Hornblende	5
		Biotite	5
		Pyroxene	<1
		Opaque	<1
Shai Hills	Gneiss	Quartz	52
		Microcline	28
		Plagioclase	14
		Biotite	5
		Muscovite	1
	Meta-Granite	Microcline	52
		Quartz	28
		Plagioclase	14
		Biotite	6

minor biotite, muscovite and accessory opaque minerals. With the exception of the plagioclase which may show alteration mostly along the twin lamina, the other minerals are relatively unaltered. Quartz is of two varieties; the dominant monocrystalline variety and the subordinate polycrystalline variety. The modal composition suggests that, the quartzo-feldspathic gneiss is dominantly 56 % quartz (Table 1). Generally, the quartz is undulose, slightly elongated and internally cracked (Fig. 3a). Micro-texture showing internal grain packing arrangement can be observed (Fig. 3b).

The rock granodiorite is grey with some dark and green spots. It is relatively fresh. The granodiorite around Amasaman is coarse grained, massive and granular and contains quartz, feldspar, biotite and pyroxene. The minerals appear to be relatively competent. It does not react with dilute HCl. In thin section, the granodiorite is texturally granular. It is coarse grained and massive. The major minerals are quartz, microcline and plagioclase together with subordinate pyroxene, biotite and hornblende (Table 1). The minerals are primary and undeformed except for quartz which shows undulose extinction and is internally cracked at places. With the exception of the biotite and amphibole, the rest of the minerals are unaltered. The biotite and hornblende show alterations mostly into chlorite and epidote respectively. In general, the minerals have regular and sharp grain boundaries (Figs. 3c and 3d).

The rock gneiss of the Goke quarry around the Shai Hills is grey, coarse grained and fresh. It is foliated, gneissic banded and composed dominantly of quartz, feldspar and biotite. This rock is structurally compact; the minerals are crystalline and appear competent. The rock is un-reactive with dilute HCl indicating the absence of probably carbonate minerals. From the thin section, the rock is coarse grained, recrystallized and foliated. This rock is composed dominantly of quartz and microcline together with plagioclase, minor biotite and muscovite (Table 1). The assemblage shows intense deformation, expressed as elongation, grain boundary granulation and brecciation (Figs. 3e and 3f). Quartz is of two varieties; the dominant coarse variety and the subordinate cryptocrystalline variety. Generally, the quartz is undulose and elongated. Microcline is coarse, poikilithic with blebs of quartz. Biotite is stretched to shredded.

The meta-Granite is also grey, clean, fresh and massive. It is crystalline, compact and appears structurally competent. The rock is coarse grained and composed of quartz, feldspars and biotite. This rock does not react with dilute HCl both in whole and powdered form. This may indicate the absence of carbonate. Microscopically, the rock is medium to coarse grained. It is granular and massive. The rock is texturally interlocking and composed dominantly of quartz and microcline that occur together with plagioclase and biotite (Table 1). Quartz occurs as coarse anhedral crystal or as blebs on microcline. It is internally cracked and exhibits undulose extinction. The feldspars are weakly altered; microcline is subhedral and poikilitic whereas plagioclase appears lathlike and altered. Biotite is tabular to blade-like and occurs as overgrowth. The photomicrographs of this rock are shown in Figs. 3g & 3h.

Observation of the mineralogical composition of the aggregates types at the two quarry sites suggest that, the aggregates at Amansaman have comparative advantage suitable for use as construction material over aggregates at Shai Hills. This is due to the presence of more stable minerals in the rocks at Amasamam (Table 1). Minerals have significant impact on the physico-mechanical properties of rock. The Mineral quartz for example is of great significance in the construction industry due to its hardness and stability. From the Bowen's reaction series, quartz is the last mineral to crystallize from molten material and the most stable rock forming mineral. This is followed by microcline, plagioclase, muscovite in that order to mention a few [43]. Rocks at the Amasaman quarry contain higher percentage of these stable minerals than rocks at the Shai Hills (Table 1). This makes the materials to have greater advantage for use as construction material.

3.2 Physical and Mechanical Properties of Aggregates

The physical and mechanical properties of aggregates vary depending on the type of lithology used in producing them. One of the major contributory factors to the quality of concrete is the quality of aggregates used in concrete mix. Since coarse aggregate is the major component of concrete mix, the quality of concrete is dependent on the inherent quality of the physico-mechanical properties of coarse aggregate. Variations in these properties affect the strength and use of coarse aggregate. Results from the analysis of the physical and mechanical properties of coarse aggregate from

Fig. 3. Photomicrographs showing important petrographic features in the investigated samples under crossed polars: (a) Quartzo-feldspathic: Very coarse quartz showing internal cracks. Note the overgrowth of biotite; (b) Quartzo-feldspathic Micro-texture showing internal grain packing and arrangement; (c) Granodiorite: showing overgrowth of biotite; (d) Granodiorite: Micro-texture showing internal grain arrangement; (e) Gneiss: Strong foliation defined by biotite and elongated quartz; (f) Gneiss: Intense deformation expressed as brecciation and grain boundary granulation; (g) Meta-Granite: Micro-texture showing grain packing and arrangement; (h) Meta-Granite: Photomicrographs showing interlocking texture

the quarry sites at Amasaman and Shai Hills together with recommended standards for concrete construction structures are presented in Table 2. It can be observed that, the EI values of aggregate from the quarry sites at Amasaman and Shai Hills are respectively 67.80% and 79.97%. The Ghana Standard Authority (GSA) stipulates that, the maximum allowable EI values is 30% for concrete building structures. Elongation index values lower than this limit are considered good, otherwise they are bad and unsuitable for a particular construction work if the values are higher [44]. The EI values from the two quarry sites are both above the maximum recommended values. Though both values are not suitable for construction work, the EI results from Amasaman quarry site show better values than those from the Shai Hills.

Flakiness is the tendency of a rock to break along a plane of weakness. This property can be estimated by the Flakiness Index value (FI). A material is considered good and suitable for use for concrete structures if the FI value is at a maximum value of 30% [44]. Flaky aggregate affects concrete mix and reduce the workability of the concrete. The results of the FI from both quarry sites as presented in Table 2 suggest that the materials can be used for concrete construction structures. However, the materials from Amasaman quarry sites are of lower values and thus considered better than those from the Shai Hills.

The aggregate impact value (AIV) for samples from Amasaman and Shai Hills quarry sites are respectively 11.81% and 12.79% (Table 2). According to BSI [45], a lower aggregate impact value indicates greater resistance to impact. Aggregate with AIV less than 20% shows that the material is of high grade for concrete construction structures. The higher the AIV, the weaker the aggregate [44]. In this study, the AIVs of aggregate from the two quarries are within the requirement for use as concrete construction materials capable of withstanding sudden shocks or impacts. However, aggregate from Amasaman quarry sites has lower AIV as compared to aggregate from Shai Hills quarry site.

The aggregate crushing value (ACV) gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. Aggregate with low ACVs shows a lower crushed fraction under load and would give a longer service life to concrete bridges on the road and hence a more economical performance. The ACVs for coarse aggregate from Amasaman and Shai Hills quarry sites are respectively 12.60% and 16.98%. The maximum recommended ACV according to the British standard is as indicated in Table 2. This suggests that the ACVs from both quarry sites are within the required standards. However, aggregate from the Amasaman quarry is of better quality than that from Shai Hills.

The Los Angeles Abrasion value (LAV) is used to indicate the toughness and abrasion characteristics of coarse aggregate. Aggregate experiences various levels of wearing and tearing throughout the life span. Aggregate should be hard and tough enough to resist crushing, degradation and disintegration

Table 2. Physico-mechanical properties of studied coarse aggregate

Location	EI (%)	FI (%)	AIV (%)	ACV (%)	LAV (%)	SG (%)	WA (%)
Amasaman Quarry	67.8	15.25	11.81	12.6	11.17	2.65	0.34
Shai Hills Quarry	79.97	28.57	12.79	16.98	16.57	2.7	0.37
GHA Standards	25% Max (Class A) and 30% Max (Classes B & C)	25% Max (Class A) and 30% Max (Classes B & C)	---	---	30% Max (Class A), 40% Max (Class B) and 45% Max (Class C)	---	1.5% Max (Class A) and 2% Max (Classes B & C)
British Standards	25% Max	25% Max	30%Max	30% Max	---	2.7	---

Elongation index: EI, Flakiness index: FI, Aggregate impact value: AIV, Aggregate crushing value: ACV, Los Angeles abrasion value: LAV, Specific gravity: SG, Water absorption: WA, GHA: Ghana Highway Authority from any associated activities including manufacturing, stockpiling, and compaction. These properties make aggregate suitable for concrete construction structures. The results of LAV test carried out in this study are shown in Table 2. The maximum recommended LAVs for concrete construction structures for materials of various classes (A, B and C, Table 2) indicate that, samples from both quarry sites have LAVs falling within the required specifications. This suggests that the coarse aggregates from both quarry sites are desirable for concrete structures. Aggregate from Amasaman quarry, however has lower LAVs than aggregate from the Shai Hills quarry.

Specific gravity (SG) of aggregates is a measure of the strength or quality of the aggregates. Aggregates with low SG are generally weaker than those with high specific SG. The average SG values of coarse aggregate as shown in Table 2 indicate a value of 2.65 for aggregate from Amasaman quarry and 2.70 for aggregate from the Shai Hills which are within the required specifications. Bulk specific gravity is useful in determining the amount of asphalt binder absorbed by the aggregates, as well as the percentage of void spaces within the aggregate [46].

The average water absorption (WA) for the aggregates from Amansaman and Shai Hills quarries are 0.34% and 0.37% respectively (Table 2). The maximum required limit for water absorption for normal concrete aggregates shows that the WA values for aggregates from both quarries are below 1% (Table 2). This implies the aggregates have very little pore spaces and will therefore absorb less water. This suggests that the samples are very fresh with high strength and competence, suitable for engineering purposes. A deformed rock is comparatively more porous than un-deformed rock. The difference in the water absorption value may be due to the intense deformation of samples from Shai Hills compared to samples from Amasaman Quarry [47,48].

3.3 Compressive Strength and Slump Test of Concretes

Results of compressive strength test performed on cast concrete cubes of aggregate with different nominal sizes from both quarries together with results of slump test are presented in Fig. 4. Generally, the compressive strength for construction varies from 15 to 30 N/mm^2 and higher in commercial and industrial structures (ASTM C39/C39M). The test provides an idea about all the characteristics of the concrete mix. According to GHA, ASTM and BSI standards and specifications, all concrete works should reach 100% strength after 28 days of curing.

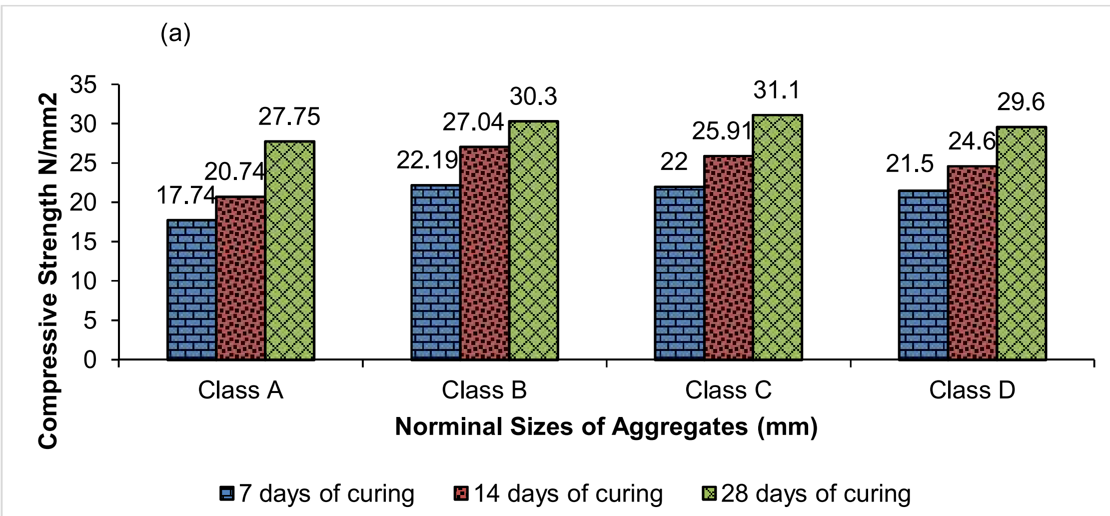
The results of compressive strength test of coarse aggregate from Amasaman quarry indicate a general trend of increase in compressive strength with increase in nominal sizes of aggregate. For example, the compressive strengths of aggregates at 28 days of curing for nominal sizes of class A (8 mm), class B (16 mm) and class C (40 mm) are 27.75 N/mm^2, 30.3 N/mm^2 and 31.1 N/mm^2 respectively (Fig. 4a). The compressive strength also increases with curing age (Fig. 4a). However, for the control experiment of nominal sizes class D (0-40 mm), though compressive strength increases with curing age, the compressive strength values of aggregates under this class of nominal sizes are lower than the strength for class C nominal sizes (the maximum aggregate sizes in this study). The reduction in the values of compressive strength could be attributed to the presence of extra fines in the concrete mix. During concrete mix design, the total amounts of fine and coarse aggregates are calculated for a batch. So, calculated proportions of fines and class D (0-40 mm) coarse aggregate constitute the aggregates component of a concrete mix, meanwhile, the fines contained in the D class (0-40 mm) coarse aggregate might have introduced more fines into the concrete mix. This increases the resulting proportion of fines in the concrete mix. In this sense, there is a reduction in the amount of coarse aggregate in the concrete mix. This study refers to mix as a reduction in coarse aggregate content. The result of compressive strength in this case defeats the observed trend of increase in strength with increase in nominal sizes of aggregate. It is thus suggestive to say that, content of coarse aggregate has influence on compressive strength of concrete. The strength values for all the three nominal sizes are within the requirement for use for general construction purposes.

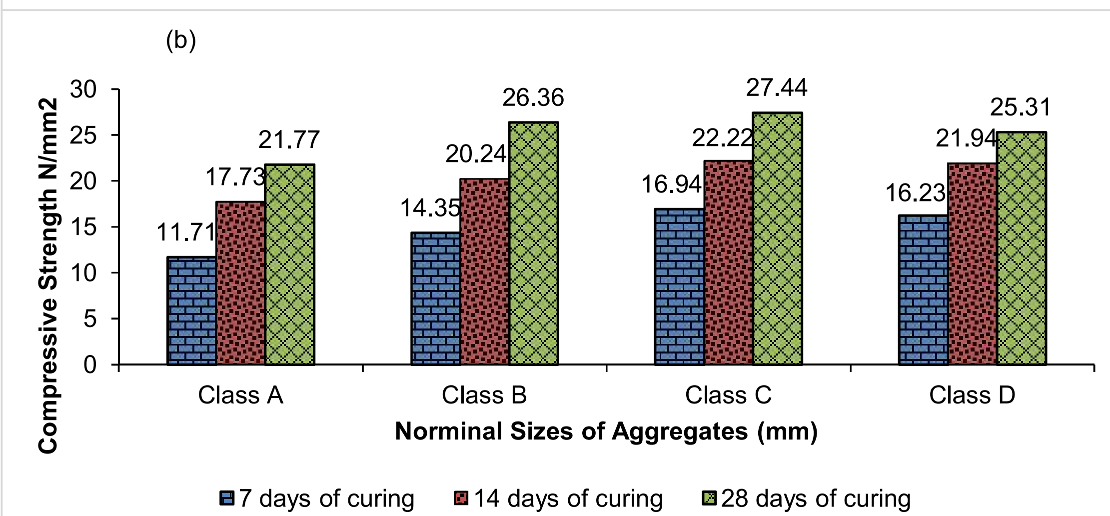
The results of compressive strength test of coarse aggregate from the Shai Hills quarry also show a general trend of increase in compressive strength with nominal sizes of aggregate. For example, the compressive strengths of coarse aggregate at 28 days of curing for nominal sizes Classes A, B and C are 21.77 N/mm^2, 26.36

N/mm² and 27.44 N/mm² respectively with corresponding increase in compressive strength with curing age (Fig. 4b). The control experiment of nominal sizes class D (0-40 mm) also shows similar trend as observed in the results from Amasaman quarry. It is therefore inferred from Figs. 4a & 4b that, aggregate sizes have impact on the compressive strength of concrete.

However, a comparative observation of the concrete test results of aggregates from the two quarry sites suggests that, the concrete specimen made from aggregate from the Amasaman area show higher compressive strength values than the aggregate from the Shai Hills quarry (Fig. 4c). This observation suggests that, aggregate type or aggregate from a particular lithology has influence on the compressive strength of concrete. The strength values for all the three nominal sizes are within the requirement for use for general construction purposes.

Fig. 4d shows the variation of slump test results for concretes produced with coarse aggregate from different quarries. The results show that, coarse aggregate size is directly proportional to the slump value or workability of fresh concrete maintained at constant concrete mix ratio of 1:1:2:4 (water: cement: fine aggregates: coarse aggregates). It can be observed that, concretes produced from coarse aggregate from Amasaman quarry have higher slump values than concretes produced from coarse aggregate from Shai Hills quarry. The highest slump result is recorded for aggregate size of 40 mm.





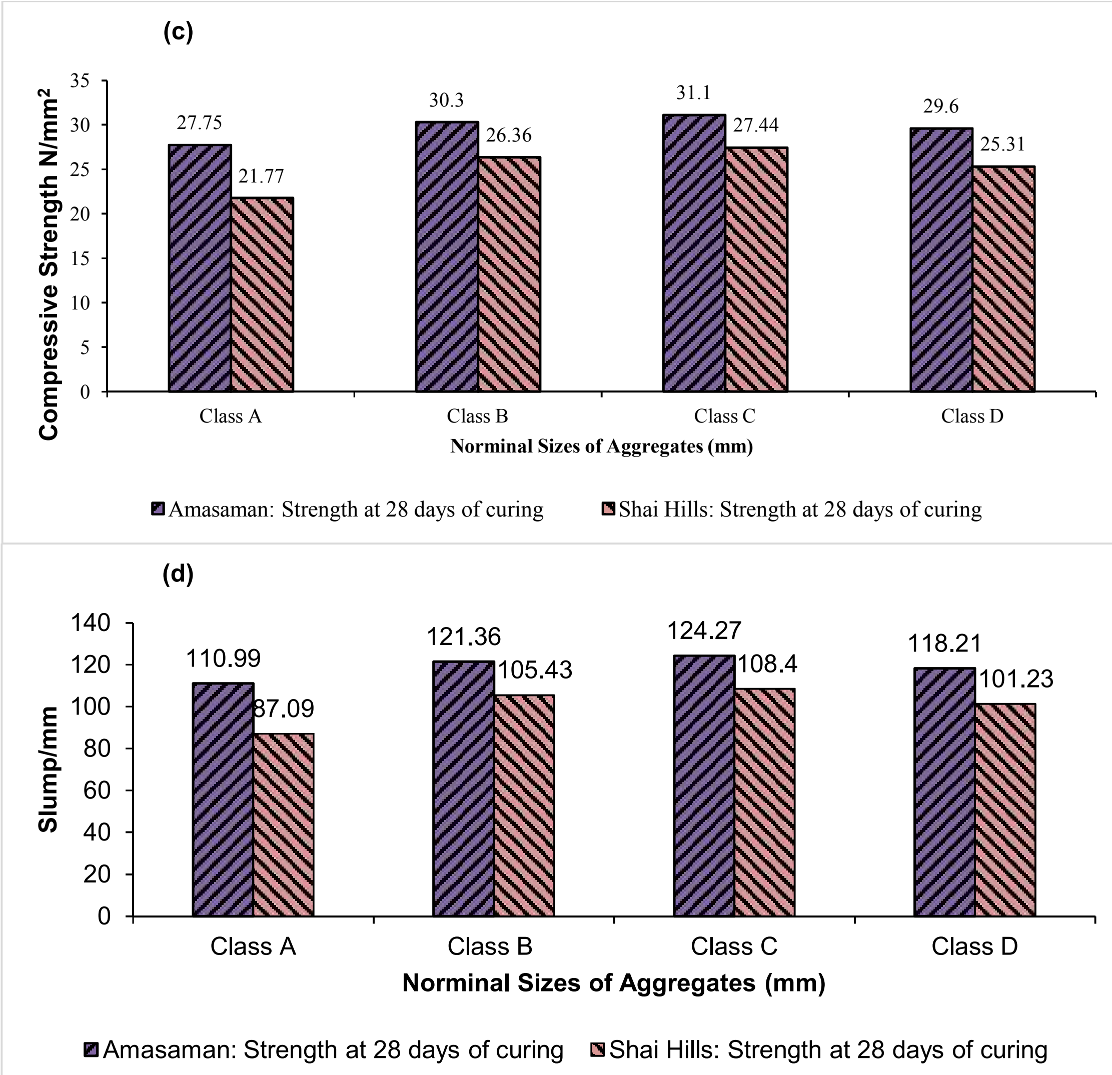


Fig. 4. (a) Compressive strength of concrete with coarse aggregate of various nominal sizes from Amasaman quarry, (b) Compressive strength of concrete with coarse aggregate of various nominal sizes from Shai Hills quarry, (c) Comparison of compressive strength of concrete with coarse aggregate from Amasaman and Shai Hills quarries, (d) Slump test of concrete.

4. CONCLUSION

- The petrographic characteristics and physico-mechanical properties of coarse aggregates from two quarry sites in the Greater Accra Region of Ghana, have been investigated to assess the impact of aggregate size, content and type on the performance characteristics of concrete. Field observations and laboratory analyses of the various parameters yielded the following conclusions:
- Petrographic studies of the two coarse aggregate sources around Amasaman and Shai Hills revealed two lithologic types each: Quartzo-feldspathic gneiss and granodiorite at Odumase quarry site and gneiss and meta-granite at Goke quarry site. Petrological and mineralogical features have significant effect on physico-mechanical properties. More stable, unaltered, un-foliated and heterogeneous aggregates give desirable engineering properties.

- Aggregates from the Amasaman quarry site have more desirable engineering properties than those at Shai Hills quarry site as revealed by the results of petrographic analysis indicating higher percentage of stable minerals, better grain arrangement, texture, mineralogical and engineering properties in aggregates from Amasaman quarry site than Shai Hills quarry site. These desirable properties are capable of producing concretes with high compressive strength.
- Physico-mechanical analyses indicate that almost all the parameters studied are within the required standards, suggesting that, aggregates from the two sources are good for use for various engineering works. The desirable properties of these parameters have significant impact on the quality of concrete when used as concrete mix.
- The increasing trend of compressive strength of concrete with increasing nominal sizes of coarse aggregate from the two quarry sources as shown by the results of compressive strength test suggests that, coarse aggregate size has profound effect on the general performance of concrete.
- The reduction in compressive strength for coarse aggregate of nominal sizes D class (0-40 mm) as compared to the strength for aggregate of nominal size C class (40 mm) for the maximum curing age of 28 days is an indication that, coarse aggregate content has an effect on the compressive strength of concrete. This is again explained from the view point that, the fine materials contained in the D class (0-40 mm) coarse aggregate might have introduced more fines into the concrete mix thereby reducing the content of coarse aggregate. This results in the net reduction in compressive strength as strength decreases with decrease in nominal sizes aggregate.
- The comparative analysis that revealed higher compressive strength values of coarse aggregate from the Amasaman quarry site than the compressive strength values of coarse aggregate from the Shai Hills quarry suggests that, aggregate type has significant influence on the compressive strength of concrete. This is also evident from the results of petrographic and physico-mechanical properties analyses, indicating that, aggregates from Amasaman quarry have better engineering properties than those from Shai Hills.

The implications from the petrographic and physico-mechanical analyses in this study are that, coarse aggregate size, content and type have significant impact on the performance characteristics of concrete.

ACKNOWLEDGEMENT

The authors are grateful to all those who in any form have contributed to the success of this work. Author LON also expresses his gratitude to his family, the Nkansah and Kersi families for their immense support during his academic pursuit. The following individuals are also greatly acknowledged for their invaluable contributions during collection and acquisition of data for this study: Mr. Dominic Kporfor of Sonitra-Ghana Limited and Mr. Kwayisi Daniel of the Department of Earth Science, University of Ghana. To Mr. Kwasi Banahene and Kwabina Ibrahim, your constant support leading to the success of this study is highly appreciated.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Shelton DP, Harper JM. An Overview of Concrete as a Building Material (Lincoln: University of Nebraska). 1982;G82-623.
2. Planete-tp. All about public. The properties of hardened concrete; 2008
3. Šahinagić-Isović M, Bijedić D, Markovski G. Shrinkage strain of concrete - causes and types 8; 2012.
4. Waziri BS, Bukar AG, Gaji YZA. Applicability of quarry sand as a fine aggregate in the production of medium grade concrete. Continental J. Engineering Science. 2011;6:1–6.
5. Abdullahi M. Effect of aggregates type on compressive strength of concrete International Journal of Civil Engineering and Structural Engineering. 2012;2:791.
6. Zhang P, Li Q, Wei H. Investigation of flexural properties of cement-stabilized macadam reinforced with polypropylene fiber” Journal of Materials in Civil Engineering. American Society of Civil Engineers (ASCE); 2010.

7. Petrounias P, Giannakopoulou P, Rogkala A, Stamatis P, Lampropoulou P, Tsikouras B, Hatzipanagiotou K. The Effect of Petrographic Characteristics and Physico-Mechanical Properties of Aggregates on the Quality of Concrete Minerals. 2018;8:577.
8. Saccani E, Photiades A, Santato A, Zeda O. New evidence for supra-subduction zone ophiolites in the Vardar zone of northern Greece: Implications for the tectonomagmatic evolution of the Vardar oceanic basin Ofioliti. 2008;33:65–85.
9. Rogkala A, Petrounias P, Tsikouras B, Hatzipanagiotou K. New occurrence of pyroxenites in the veria naousa ophiolite (North Greece): Implications on their origin and petrogenetic evolution Geosciences. 2017;7:92.
10. Piasta W, Góra J, Turkiewicz T. Properties and durability of coarse igneous rock aggregates and concretes Constr. Build. Mater. 2016;126:119–129
11. Özturan T, Çeçen C. Effect of coarse aggregate type on mechanical properties of concretes with different strengths Cem. Concr. 2007;27:165–170
12. Kiliç A, Atis CD, Teymen A, Karahan O, Özcan F, Bilim C, Özdemir M. The influence of aggregate type on the strength and abrasion resistance of high strength concrete Cement Concr. Comp. 2008;30:290 296.
13. Gonilho Pereira C, Castro-Gomes J, Oliveira L. Influence of natural coarse aggregate size, mineralogy and water content on the permeability of structural concrete Constr. Build. Mater. 2009;23:602–608.
14. Chegbeleh LP, Ackah FS. Chemical stabilization of black cotton clay and laterite soil using drycon powder for suitability as construction materials. Journal of Geography, Environment and Earth Science International. 2020;29–39.
15. Yao Y, Robb LJ. The Birimian granitoids of Ghana: a review (University of the Witwatersrand); 1998.
16. Taylor PN, Moorbath S, Leube A, Hirdes W. Early Proterozoic crustal evolution in the birimian of Ghana: constraints from geochronology and isotope geochemistry. Precambrian Research. 1992;56:97–111.
17. Hirdes W, Davis DW. First U–Pb zircon age of extrusive volcanism in the Birimian Supergroup of Ghana, West Africa J. Afr. Earth Sci. 1998:27:291–294.
18. Anum S, Sakyi PA, Su B-X, Nude PM, Nyame F, Asiedu D, Kwayisi D. Geochemistry and geochronology of granitoids in the Kibi-Asamankese area of the Kibi-Winneba volcanic belt, southern Ghana. Journal of African Earth Sciences. 2015;102:166–79
19. Cordani UG, D'Agrella-Filho MS, Brito-Neves BB, Trindade RIF. Tearing up Rodinia: The Neoproterozoic palaeogeography of South American cratonic fragments Terra Nova. 2003;15: 350–9.
20. Hoffman PF. Did the Breakout of Laurentia Turn Gondwanaland Inside-Out? Science. 1991;252:1409–12.
21. Attoh K, Corfu F, Nude PM. U-Pb zircon age of deformed carbonatite and alkaline rocks in the Pan-African Dahomeyide suture zone, West Africa Precambrian Research. 2007;155:251–60
22. Attoh K. High-Pressure Granulite Facies Metamorphism in the Pan-African Dahomeyide Orogen, West Africa The Journal of Geology. 1998;106:236–46.
23. Attoh K. Models for orthopyroxene–plagioclase and other corona reactions in metanorites, Dahomeyide orogen, West Africa Journal of Metamorphic Geology. 1998;16:345–62.
24. Ganesha AV, Narasimha KNP, Krishnaiah C. Petrographic And Physico-Mechanical Studies On Granitic Rocks Around Bidadi, Ramanagaram Taluk, Karnataka State. 2016;3(5).
25. [ASTM 2003 ASTM C 295 -03; Guide for petrographic examination of aggregates for concretes vol 4 (Annual Book of ASTM Standards).
26. Petrounias P, Giannakopoulou P, Rogkala A, Lampropoulou P, Koutsopoulou E, Papoulis D, Tsikouras B, Hatzipanagiotou K. 2018 The Impact of Secondary Phyllosilicate Minerals on the Engineering Properties of Various Igneous Aggregates from Greece Minerals. 2018;8:329.
27. Petrounias P, Giannakopoulou PP, Rogkala A, Stamatis PM, Tsikouras B, Papoulis D, Lampropoulou P, Hatzipanagiotou K. The influence of alteration of aggregates on the quality of the concrete: A case study from serpentinites and andesites from central

Macedonia (North Greece) Geosciences. 2018;8:115.
28. Buravchuk NI, Guryanova OV, Jani MA, Putri EP. The Influence of the Activity of the Mineral Additives on Physico-mechanical Properties of Concrete Compositions Advanced Materials (Springer). 2019;147–159.
29. ASTM ASTM C. Guide for petrographic examination of aggregates for concretes, Annual Book of ASTM Standards. 2003;04(02):295-03.
30. BSI 1990 BS 812-109:1990 Testing aggregates. Methods for determination of moisture content (BSI, LONDON UK).
31. BSI 1995 BS 812-2: Testing aggregates. Methods for determination of density (London, UK); 1995.
32. B.S. 1989 BS 812-105.1:1989 Testing aggregates. Methods for determination of particle shape. Flakiness index (London, UK).
33. B.S. 1990 BS 812-105.2:1990 Testing aggregates. Methods for determination of particle shape. Elongation index of coarse aggregate.
34. B.S. 1990 BS-812, part 111, 1990, Methods for determination of ten percent fines value (TFV (London, UK).
35. BSI 1990 BS-812, Part 110, 1990, Methods for determination of aggregate crushing value (ACV) (London, UK).
36. Kahraman S, Fener M. Predicting the Los Angeles abrasion loss of rock aggregates from the uniaxial compressive strength Materials Letters. 2007;61:4861–4865.
37. BSI 1983 BS1881-116: Method for determining compressive strength (London: BSI).
38. BSI 1983 BS 1881-108: Method for making test cubes from fresh concrete. (London: BSI).
39. BSI 2013 BS 1881-130:2013 - Testing concrete. Method for temperature-matched curing of concrete specimens (Lincoln: BSI).
40. Tam CT, Deneti SB, Li W. EN 206 Strength conformity for sustainable concrete construction. 40th Conference on Our World In Concrete & Structures (Singapore, CI-Premier, Singapore,). 2015;459-465.
41. Alam T 2020 Main Properties of Concrete for Construction Civil Engineering.
42. BSI. 1983;1881-102. Testing Concrete-Method for determination of slump (London: BSI).
43. Milovsky A V and Kononov O V 1985 Mineralogy (Moscow: Mir Publisher).
44. Amoako K, Ahenkorah I, Baffoe E, Kubi B, Mends LG, Asebiah DC. Engineering Characterisation of Aggregates from Some Selected Areas in Kumasi, Ghana International Journal of Advanced Engineering, Management and Science. 2018;4:295–304.
45. BSI 1992 BS 882-2: Specification for aggregates from natural sources for concrete (London: BSI).
46. Neville A M 1995 *Properties of Concrete* (London, UK: Pitman)
47. Kutu JM, Hayford EK, Oddei JK, Gadasu A. 2014. Characterization of engineering rock materials from the shai akuse district, south eastern Ghana. Journal of Ghana Science Association 15.
48. Singh P 2008 Engineering materials (Anand, Gujarat: Charotar publisher).

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/60396